INTEGRATED OCEAN OBSERVING SYSTEM

Manual for

Real-Time Quality Control of In-Situ Current Observations

A Guide to Quality Control and Quality Assurance of Acoustic Doppler Current Profiler Observations

Version 1.0
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QARTOD
QUALITY ASSURANCE OF REAL-TIME OCEANOGRAPHIC DATA

Document Validation

U.S. IOOS Program Office Validation

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Joseph Swaykos, NOAA National Data Buoy Center	Date

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Chris Paternostro, NOAA NOS Center for Operational Oceanographic Products and Services (CO-OPS)	Date

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Revision History

Date	Revision Description	Notes
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Through the process of five workshops of the Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD), these quality control steps were adapted from existing guidelines of NOAA's National Data Buoy Center (NDBC) and the Center for Operational Oceanographic Products and Services (CO-OPS), the U.S. Army Corps of Engineers Field Research Facility (USACE FRF), and participating manufacturers of current measuring systems—Nortek, SonTek, and Teledyne RDI. Additionally, the individual tests have been mapped to existing tests of UNESCO (1993).

QARTOD Meetings

QARTOD I: National Data Buoy Center, Stennis Space Center, Mississippi. 3-5 December 2003

QARTOD II: Norfolk, Virginia. 28 Feb-2 Mar 2005

QARTOD III: Scripps Institute of Oceanography, La Jolla, California, 2-4 November 2005

QARTOD IV: Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. 21-23 June 2006

QARTOD V: Omni Hotel, Atlanta, Georgia, 17-19 November 2009.

Agendas, attendees, and reports from QARTOD meetings are located at www.ioos.noaa.gov/qartod/meetings.html.

Acronyms and Abbreviations

ACT	Alliance for Coastal Technologies
ADCP	Acoustic Doppler Current Profiler
ADP	Acoustic Doppler Profiler
AOOS	Alaska Ocean Observing System
AST	Acoustic Surface Tracker
AWAC	Acoustic Waves and Currents
BOA	Board of Advisors
CariCOOS	Caribbean Coastal Observing System
CeNCOOS	Central and Northern California Ocean Observing System
CO-OPS	Center for Operational Oceanographic Products and Services
DMAC	Data Management and Communications
GCOOS	Gulf of Mexico Coastal Ocean Observing System
GLOS	Great Lakes Observing System
GOOS	Global Ocean Observing System
IMOS	Integrated Marine Observing System
IOC	Intergovernmental Oceanographic Commission
IODE	International Oceanographic Date Exchange
IOOC	Interagency Ocean Observing Committee
IOOS	Integrated Ocean Observing System
MARACOOS	Mid-Atlantic Regional Association Coastal Ocean Observing System
MBARI	Monterey Bay Aquarium Research Institute
NANOOS	Northwest Association of Networked Ocean Observing Systems
NCDDC	National Coastal Data Development Center
NDBC	National Data Buoy Center
NERACOOS	Northeastern Regional Association of Coastal Ocean Observing Systems
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
PacIOOS	Pacific Islands Ocean Observing System
QARTOD	Quality Assurance/Quality Control of Real-Time Oceanographic Data
QA	Quality Assurance

QC	Quality Control
RA	Regional Association
RCOOS	Regional Coastal Ocean Observing System
SCCOOS	Southern California Coastal Ocean Observing System
SAIC	Science Applications International Corporation
SD	Standard Deviation
SECOORA	Southeast Coastal Ocean Observing Regional Association
TRDI	Teledyne RD Instruments
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USACE FRF	U.S. Army Corps of Engineers, Field Research Facility, [Duck, NC]
WHOI	Woods Hole Oceanographic Institution

1.0 Background and Introduction

The U.S. Integrated Ocean Observing System (IOOS) has a vested interest in collecting high quality data for the 26 core variables (U.S. IOOS 2010) measured on a national scale. In response to this interest, U.S. IOOS continues to establish written, authoritative procedures for the quality control (QC) of real-time data through the Quality Assurance/Quality Control of Real-Time Oceanographic Data (QARTOD) program, addressing each variable as funding permits. This manual is the third in a series of guidance documents that address QC of real-time data of each core variable.

Please refer to http://www.ioos.noaa.gov/qartod/for the following documents.

1.) U.S IOOS QARTOD Project Plan dated April 1, 2012

2.) U.S. Integrated Ocean Observing System, 2012. Manual for Real-Time Quality Control of Dissolved Oxygen Observations: A Guide to Quality Control and Quality Assurance for Dissolved Oxygen Observations in Coastal Oceans. 45pp.

Please reference this document as:

> U.S. Integrated Ocean Observing System, 2013. Manual for Real-Time Quality Control of In-Situ Current Observations: A Guide to Quality Control and Quality Assurance of Acoustic Doppler Current Profiler Observations. 45pp.

This document follows and expands on the National Surface Currents Plan (U.S. IOOS 2009). The U.S. Army Corps of Engineers (USACE), and the National Oceanic and Atmospheric Administration's (NOAA) National Data Buoy Center (NDBC) and Center for Operational Oceanographic Products and Services (CO-OPS), well-recognized as established providers of current data, have long led the nation with current observation programs. NDBC and CO-OPS have decades of experience applying QC checks for hundreds of deployments (NDBC 2009). However, the observation locations were based on local project or user requirements, resulting in a useful but ad hoc network with limited integration. The National Surface Currents Plan addresses this situation by defining a comprehensive currents observing network for the United States.

The National Surface Currents Plan documents the extensive effort that QARTOD workshops devoted to QC of currents data. The process for the development, distribution, review, refinement, and revision of this manual continues the QARTOD effort through collaboration by the QARTOD Board of Advisors, all the U.S. IOOS Regional Associations (RAs), manufacturers, and operators. Operators, individuals or entities who are responsible for collecting and providing currents data, are a key part of this endeavor.

This manual is a living document that reflects the state-of-the-art QC testing procedures for currents observations. It is written for the experienced operator but also provides examples for those who are just entering the field.

2.0 Purpose/Constraints/Applications

This manual documents a series of test procedures for data QC of ocean currents. Current observations covered by these procedures are collected in oceans and lakes in real time or near-real time. The scope of real time has expanded to accommodate the span of the 26 variables covered by IOOS. The characteristics of real time (in no particular order) are:

- data are delivered without delay for immediate use;
- a time series extending only backwards in time, where the next data point is not available; and
- delays occurring within from a few seconds to a few hours or even days, depending upon the variable.

High quality marine observations require sustained quality assurance (QA) and QC practices to ensure credibility and value to operators and data users. QA practices involve processes that are employed with hardware to support the generation of high quality data, such as a sufficiently accurate, precise, and reliable sensor with adequate resolution. Other practices include: sensor calibration; calibration checks, and/or in-situ verification, including post deployment calibration; proper deployment considerations, such as measures for corrosion control and anti-fouling; solid data communications; adequate maintenance intervals; and creation of a robust quality control process. Post-deployment calibration (instrument verification after recovery) issues are not part of the scope of this manual. Although QC and QA are interrelated and important to the process, QA issues are addressed separately in appendix A.

QC involves follow-on steps that support the delivery of high quality data and requires both automation and human intervention. QC practices include such things as format, checksum, timely arrival of data, threshold checks (minimum/maximum rate of change), neighbor checks, climatology checks, model comparisons, signal/noise ratios, verification of user satisfaction, and generation of data flags (Bushnell 2005).

These procedures are written as a high-level narrative from which a computer programmer can develop code to execute specific data flags (data quality indicator) within an automated software program. This manual is also a deliverable to the U.S. IOOS RAs and ocean observing community and represents a contribution to a collection of core variable QC documents.

This manual presents a series of tests for QC procedures. The goal is to provide guidance to the U.S. IOOS and the currents community at large on an agreed-upon, documented, and implemented standard process. U.S. IOOS/QARTOD maintains a code repository (www.ioos.noaa.gov/qartod) where operators may find or post examples of code in use. Although certain tests are recommended, thresholds can vary among data providers. In some instances, tests have been simplified and are less rigorous than those implemented by established providers of current data, such as CO-OPS, NDBC, and USACE. A balance must be struck between the time-sensitive needs of real-time observing systems and the degree of rigor that has been applied to non-real-time systems by operators with decades of QC experience.

These submitted tests apply only to the in-situ, real-time measurement of surface currents as observed by sensors deployed on fixed or moored platforms and not to sensors deployed on moving platforms (e.g., drifting buoys, autonomous marine vehicles, ships) or remotely sensed current measurements (e.g., high frequency radar).

Through the process of the first four QARTOD workshops, a set of guidelines were collected and submitted to the Ocean.US Data Management and Communications (DMAC) Steering Committee (Bouchard et al. 2007). Those guidelines were adapted from existing guidelines developed and implemented by established providers of currents data, as well as participating manufacturers of current-measuring systems—Nortek, SonTek, and Teledyne RDI. Additionally, the individual tests have been mapped to existing tests of UNESCO (1993).

The following list includes currents data providers and manufacturers who contributed to developing this manual. Also included is the specific sensor associated with the data provider/vendor. This list is not intended to be comprehensive but as a means to acknowledge the efforts of these operators and manufacturers.

- Woods Hole Oceanographic Institution, NDBC, University of South Florida (Teledyne RDI 1200, 600, 300, 75, and 38 kHz Acoustic Doppler Current Profilers)
- CO-OPS (Teledyne RDI 1200, 600, and 300 ADCP; Nortek Aquadopp; SonTek 1000, 500, and 250 ADP Acoustic Doppler Current Meter)
- USACE FRF (TRDI, Nortek Aquadopp)
- University of South Florida (TRDI)
- Shell Oil Company (TRDI)

The process of ensuring data quality is not always straightforward. QA and QC procedures may be specific to a sensor technology or even to a particular manufacturer's model, so the establishment of a methodology that is applicable to every sensor is challenging.

2.1 Data Processing Methodology

The type of sensor system used to collect the data and the system used to process and transmit the information impact the QC algorithms that can be used on the data. In-situ systems with sufficient on-board processing power within the sensor and limited data transmission capability may process the original (raw) measurement and produce product summaries, such as mean currents. If ample transmission capability is available, the entire raw data stream may be transmitted ashore and subsequently quality controlled from there.

Therefore, because operators have different data processing methodologies, several levels of QC are proposed.

2.2 Traceability to an Accepted Standard

To ensure that ADCPs are producing accurate data, rigorous calibrations and calibration checks must be performed. Most operators rely upon vendor calibrations and conduct calibration checks, which are also usually described in their user manuals. These activities fall currently within the realm of QA and are further addressed in appendix A.

Calibrations and calibration checks must be traceable to accepted standards. The National Institute of Standards and Technology (NIST), a provider of internationally accepted standards, is often the source for accepted standards, but there is no standard for measurement of currents. These activities must rely upon the fundamental standards for length, time, and the earth's magnetic field. Fortunately, traceability to NIST is relatively easy because the standards for length, time, and compass-bearing are readily available at the resolutions required.

2.3 Hardware Limitations

Advances in ADCP sensor technology have eliminated many of the problems encountered in older devices. Sensors are now smaller, more reliable, and draw less power. More sensors can be employed to make corrections, and most notably, signal processing hardware and software capabilities have grown enormously.

ADCP current sensors can withstand moderate bio-fouling, but observational accuracy gradually degrades as marine growth becomes excessive. As the bio-mass increases on the ADCP, effective acoustic power output and transducer reception sensitivity also degrades, leading to reduced signal-to-noise ratios and less accurate observations. ADCPs using pressure sensors may find dampened output as the orifice becomes obstructed. However, in some instances, effective antifouling materials and coatings may permit system deployments in excess of two years.

ADCPs are depth/range limited in two fundamental ways: 1) the simple acoustic signal strength loss over distance (higher frequency systems have shorter ranges) and 2) the acoustic beams spread with increasing range, both within an individual beam and among the multiple beams, which leads to reduced resolution and less certainty that the sampled field has uniform flow. Many of the QC tests address these limitations through the use of carefully selected thresholds and other test criteria.

ADCP transducer side lobe reflections must also be considered. These reflections can come from the bottom, the surface, or adjacent structures and degrade ADCP performance. These errors are mitigated by proper deployment procedures. Manufacturer user manuals should be consulted to ensure that proper procedures are followed.

Corrections for magnetic declination and deviation are important and must be given careful consideration. Although these corrections are beyond the scope of this manual, manufacturers provide processes for making corrections, which are specific to the sensor make/model, within their user manuals.

3.0 Quality Control

To conduct real-time QC on current observations, the first pre-requisite is to understand the science and context within which the measurements are being conducted. Currents are dependent upon many things such as tidal forces, density gradients, and winds. The real-time QC of these observations can be extremely challenging. Human involvement is therefore important to ensure that solid scientific principles are applied to the process to ensure that good data are not discarded and bad data are not distributed. Examples include selection of appropriate thresholds and examination of data flagged as questionable.

This manual focuses specifically on real-time data, so the operator is likely to encounter aspects of data QC where the flags and tests described in the following sections do not apply because the data are not considered to be real-time. For example, for real-time QC, drift (slow changes in sensor calibration) cannot be detected or corrected. Fortunately, sensor drift and drift correction are not typically issues for ADCPs (except for clock drift). Another example might be the ability of some data providers to backfill data gaps. In both of these examples, the observations are not considered to be real-time for purposes of QC checks.

3.1 QC Flags

Data are evaluated using QC tests, and the results of those tests are recorded by inserting flags in the data files. Table 3-1 provides a simple set of flags and associated descriptions. Operators may incorporate additional flags for inclusion in metadata records. For example, an observation may fail the Current Speed Test (Test 10) and be flagged as having failed the test. Additional flags may be incorporated to provide more detailed information to assist with troubleshooting. If the data failed the Current Speed Test by exceeding the upper limit, a "failed high" flag may indicate that the values were higher than the expected range, but such detailed flags primarily support maintenance efforts and are presently beyond U.S. IOOS requirements for QC of real-time data.

Further post-processing of the data may yield different conclusions from those reached during initial assessments. Flags set in real time should not be changed to ensure that historical documentation is preserved. Results from post processing should generate another set of flags.

Observations are time ordered, and the most recent observation is n_0, preceded by a value at n_{-1}, and so on backwards in time. The focus of this manual is primarily on the real-time QC of observations n_0, n_{-1}, and n_{-2}.

Table 3-1 Flags for real-time data from ADCPs. (UNESCO 2013)

Flag	Description
Pass=1	Data have passed critical real-time QC tests and are deemed adequate for use as preliminary data.
Not evaluated=2	Data have not been QC-tested, or the information on quality is not available.
Suspect or Of High Interest=3	Data are considered to be either suspect or of high interest to operators and users. They are flagged suspect to draw further attention to them by operators.
Fail=4	Data are considered to have failed one (or more) critical real-time QC check. If they are disseminated at all, it should be readily apparent that they are not of acceptable quality.
Missing data=9	Data are missing; used as a placeholder.

3.2 Sensor Deployment Considerations

ADCPs can be mounted in a variety of configurations:

- in a platform sitting on the bottom, looking upward
- on a buoy, looking downward
- attached to a structure, looking horizontally
- on a fixed oil rig, looking in any direction
- aboard a vessel underway
- upward or downward on an in-line mooring.

Acoustic Doppler current meters and profilers may have two (the minimum required for horizontal profiling), three, four or more transducers. In some cases, redundant transducers over-resolve the current measurements, and the results are used to provide an estimate of the quality of the observations. In other cases, multiple transducer pairings utilize different transmit frequencies and provide the benefits of longer range from a lower frequency and higher spatial resolution from the higher frequency. Examples of the variety of transducer configurations are shown in figs. 3-1 through 3-5. This manual does not cover the QC of all possible configurations, but it does include the most widely used tests provided by participating operators. Notes within each specific test provide application guidance.

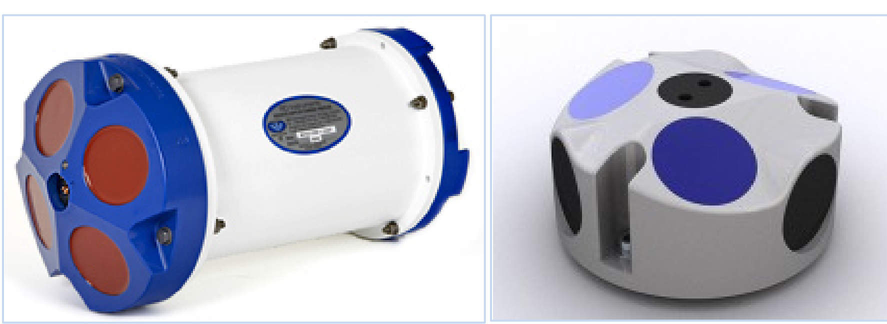

Figure 3-1. Teledyne RD Instruments ADCP (left); Nortek Aquadopp transducer head (right).

Figure 3-2. SonTek ADP (left); Aanderaa Doppler current sensors (right).

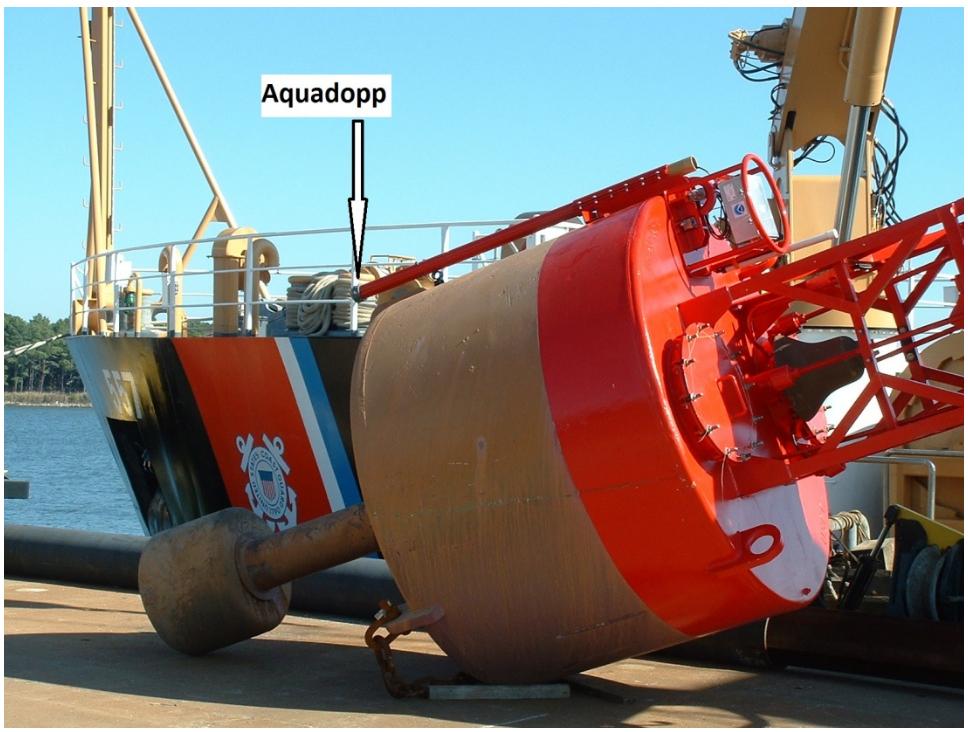

Figure 3-3. A Nortek Aquadopp is fastened to a standard U.S. Coast Guard aid to navigation. Photo courtesy of Mark Bushnell (NOAA).

Figure 3-4. A bottom-mounted Nortek AWAC is prepared for deployment. Photo courtesy of Doug Wilson (NOAA).

Figure 3-5. A SonTek side-looking ADP is raised for cleaning. Photo courtesy of Warren Krug (NOAA).

3.3 QC Test Types and Hierarchy

This section outlines the 18 real-time QC tests that are required and recommended for in-situ currents. Tests are listed in table 3-2 and are divided into four groups according to test type. The tests in group 1 (table 3-3) are required (where possible) for all current measurements collected for U.S. IOOS. However, the output of some instruments is not sufficient for some tests. Operators must consider each test in group 2 to determine if it can be applied in their particular instance—not all tests can be implemented in all situations. Operators should also consider that some of these tests can be carried out within the instrument, where thresholds can be defined in configuration files. Although more tests imply a more robust QC effort, there are many reasons operators could use to justify not conducting some tests. In those cases, operators need only to document reasons these tests do not apply to their observations. Such flexibility is needed to support the emerging U.S. IOOS certification effort, since the number of tests conducted and the justification for not applying some tests are useful for evaluating an operator's skill levels. Even though currently there are no suggested tests, Group 3 is retained as a placeholder for possible future additions.

Table 3-2. QC tests for real-time data from ADCPs and buoy-mounted sensors

Test Type	Test Name	Status
Sensor Health	Battery Power (Test 1)	Strongly Recommended
	Check Sum (Test 2)	Required
	Sensor Tilt (Test 3)	Required
	Speed of Sound (Test 4)	Required
Signal Quality	Noise Floor (Test 5)	Strongly Recommended
	Signal Strength (Test 6)	Required
	Signal to Noise (Test 7)	Strongly Recommended
	Correlation Magnitude (Test 8)	Strongly Recommended
	Percent Good (Test 9)	Strongly Recommended
Current Velocity	Current Speed (Test 10)	Required
	Current Direction (Test 11)	Required
	Horizontal Velocity (Test 12)	Required
	Vertical Velocity (Test 13)	Strongly Recommended
	Error Velocity (Test 14)	Strongly Recommended
	Stuck Sensor (Test 15)	Required
Overall Profile	Echo Intensity (Test 16)	Required
	Echo Intensity Range Drop-off (Test 17)	Strongly Recommended
	Current Gradient (Test 18)	Strongly Recommended

Table 3-3. QC tests in order of requirement hierarchy

Group 1 Required	Check Sum (Test 2) Sensor Tilt (Test 3) Speed of Sound (Test 4) Signal Strength (Test 6) Current Speed (Test 10) Current Direction (Test 11) Horizontal Velocity (Test 12) Stuck Sensor (Test 15) Echo Intensity Test (16)
Group 2 Strongly Recommended	Battery Power (Test 1) Noise Floor (Test 5) Signal-to-Noise (Test 7) Percent Good (Test 9) Error Velocity Test (14) Correlation Magnitude (Test 8) Vertical Velocity Test (13) Range Drop-off Test (17) Current Gradient Test (18)
Group 3 Suggested	

Some effort will be needed to select the best thresholds, which are determined at the operator level and may require trial and error/iteration before final selections are made. A successful QC effort is highly dependent upon selection of the proper thresholds, which should not be determined arbitrarily but can be based on historical knowledge or statistics derived from more recently acquired data. Although this manual provides some guidance for selecting thresholds based on input from various operators, it is assumed that operators have the subject matter expertise as well as a sincere interest in selecting the proper thresholds to maximize the value of their QC effort. Operators are required to openly provide thresholds as metadata for user support. This shared information will help U.S. IOOS to document standardized thresholds to be included in future releases of this manual.

3.4 QC Test Descriptions

A variety of tests can be performed on the sensor measurements to evaluate data quality. Testing the integrity of the data transmission is a first step. If the data are corrupted during transmission, further testing may be irrelevant. The checks defined in these 18 tests evaluate data through various comparisons to other data and to the expected conditions in the given environment. The tests listed in this section presume a time ordered series of observations and denote the most recent observation as preciously described.

For each test described, i represents the bin number, with bin one being closest to the instrument, and j represents the beam number.

3.4.1 Sensor Health Tests

Each test checks the sensor to ensure that everything is working properly.

Battery Power (Test 1) – Strongly Recommended

Check for sufficient battery voltage		
Test determines that there is sufficient battery power (BATTPOW) to provide a "good" measurement.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	Battery power is less than an accepted minimum value (MIN).	If BATTPOW < MIN, flag = 4
Suspect = 3	N/A	
Pass = 1	Battery power is sufficient.	If BATTPOW ≥ MIN, flag = 1
Test exception: Test cannot be applied when no battery measurement is provided.		
Test specifications to be established by operator. **Example 1:** MIN = 11.6 VDC **Example 2:** RDI, MIN = 150 battery counts		

Check Sum (Test 2) - Required

Check for data message integrity		
Test to ensure that the message transmitted from the sensor is valid. A checksum value (CHECKSUM) is prepared from the message before it is transmitted and appended to the data stream. Once received, a checksum is calculated from the message and that value is compare to the transmitted value.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	The data message fails if the calculated checksum, CKSUMCAL, from the data stream does not match the transmitted checksum, CKSUMXMT, in the message.	IF CKSUMCAL ≠ CKSUMXMT, flag =4
Suspect = 3	N/A	None
Pass = 1	The data message is valid if the calculated checksum, CKSUMCAL, is identical to the transmitted checksum, CKSUMXMT.	IF CKSUMCAL = CKSUMXMT, flag = 1
Test exception: Test cannot be applied when no checksum or other message integrity verification is provided.		
Example: CHECKSUMXMT = FF4A, CHECKSUMCAL = FF4A, flag = 1		

Sensor Tilt (Test 3) - Required

Check for unexpected tilt or change in tilt		
Current sensors must be aligned within an expected range of tilt angles to properly measure horizontal and vertical currents. Sensors with the capability to measure tilt along two axes should undergo this sensor tilt test to ensure that the measurements are collected within the correct range of values.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	Tilt (TILTX, TILTY) angle is greater than the allowed value (TILTMAX).	If TILTX > TILTMAX OR TILTY > TILTMAX, flag = 4
Suspect = 3	N/A	
Pass = 1	Tilt angle is less than or equal to the allowed value.	If TILTX ≤ TILTMAX OR TILTY ≤ TILTMAX, flag = 1
Test Exception: Test cannot be applied when no tilt value is provided in real-time data stream.		
TILTMAX values provided by manufacturer. **Example**: TILTMAX = 15°, TILTX = 3, TILY = 1, Flag = 1		

Speed of Sound (Test 4) - Required

Check for a valid speed of sound value.		
The speed of sound value (SSVAL) is used in the calculation of acoustic pulse travel times and must be within a reasonable range (SSMIN and SSMAX).		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	If the speed of sound value SSVAL is outside of acceptable sound speed range, SSMIN to SSMAX, the SSVAL is not valid.	IF SSVAL.LT .SSMIN OR SSVAL > SSMAX, flag = 4
Suspect = 3	N/A	None
Pass = 1	If the speed of sound value SSVAL is within the acceptable sound speed range, SSMIN to SSMAX, the SSVAL is valid.	IF SSVAL ≥ SSMIN AND SSVAL ≤ SSMAX, flag = 1
Test Exception: None.		
Test specifications to be established locally by operator: SSMIN and SSMAX **Example:** SSMIN = 1475 m/s, SSMAX = 1560 m/s, SSVAL = 1528 m/s, flag = 1		

3.4.2 Signal Quality Tests

Signal quality tests are applied to each beam of the sensor and to each depth level that is transmitted by the sensor.

Noise Floor (Test 5) – Strongly Recommended

Ensure that measured values of signal are above the noise value.		
System noise within each of the beams (SCMNOIS[*j*]) should be within a specified range of values. If any of the beams fail the test, the sensor fails the test and should not be used.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	System noise values, SCMNOIS(*j*) are outside a count range.	If SCMNOIS(*j*) < COUNTMIN OR SCMNOIS(*j*) > COUNTMAX, flag (*j*) = 4
Suspect = 3	N/A	
Pass = 1	System noise values, SCMNOIS(*j*) are within a count range.	If SCMNOIS(*j*) ≥ COUNTMIN AND SCMNOIS(*j*) ≤ COUNTMAX, flag (*j*) = 1 All flags must equal 1, FLAG(1) = FLAG(2) = FLAG(3) = 1 to continue
Test Exception:		
Test specifications to be established locally by operator **Example:** Operators to provide examples as procedures are implemented.		

Signal Strength (Test 6) - Required

Ensure that the signal strength, SCMDB(*j*), is sufficient to produce good data.		
Signal strength within each of the beams, SCMDB(*j*), should be above a specified range of threshold (SCMDBMIN). At least three beams must pass this test for vertical profiling, and at least two beams are required for horizontal profiling.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	Signal strength values, SCMDB(*j*), for each beam, *j*, are greater than a minimum value.	IF SCMDB(*j*) < SCMDBMIN, flag = 4
Suspect = 3	N/A	
Pass = 1	Signal strength values exceed the minimum value for good data.	IF SCMDB(*j*) ≥ SCMDBMIN, flag = 1
Test Exception:		
Test specifications to be established by the manufacturer. **Example:** Operators to provide examples as procedures are implemented.		

Signal-to-Noise (Test 7) – Strongly Recommended

Test that the signal-to-noise ratio is sufficient		
The signal to noise ratio value (SNRVAL[*i*]) should exceed a operator prescribed value (SNRMIN) for each bin for the measurements to be valid.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	If the SNRVAL is less than the operator-provided SNRMIN, the measurement is not valid.	If SNRVAL < SNRMIN, flag = 4
Suspect = 3	N/A	None
Pass = 1	Applies for test pass condition.	If SNRVAL ≥ SNRMIN, flag = 1
Test Exception: None.		
Test specifications to be established locally by operator. **Example:** Operators to provide examples as procedures are implemented.		

Correlation Magnitude (Test 8) – Strongly Recommended

Test that correlation magnitude is above an acceptable threshold		
A key quality control parameter for broadband ADCPs, such as the TRDI ADCPs, is the correlation magnitude (CMAG). This is essentially a measurement of how much the particle distribution has changed between phase measurements. The less the distribution has changed, the higher the correlation, and the more precise the velocity measurement. Correlation magnitude is provided for each bin (*i*) and each beam (*j*).		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	If the correlation magnitude (CMAG[*i*,*j*]) falls below a certain count level (CMAGMIN), the measurement for that bin and beam fails.	If CMAG(*i*,*j*) < CMAGMIN, flag = 4
Suspect = 3	If the correlation magnitude (CMAG[*i*,*j*]) is between the minimum (CMAGMIN) and maximum (CMAGMAX) count levels, the measurement for that bin and beam passes, but is considered suspect.	IF CMAG(*i*,*j*) ≥ CMAGMIN AND CMAG(*i*,*j*) ≤ CMAGMAX, flag = 3
Pass = 1	If the correlation magnitude (CMAG[*i*,*j*]) is above a maximum count level (CMAGMAX), the measurement for that bin and beam passes.	IF CMAG(*i*,*j*) > CMAGMAX, flag = 1
Test Exception: This test is primarily for the TRDI ADCP sensors		
Test specifications to be established by the manufacturer. **Example :** Operators to provide examples as procedures are implemented.		

Percent Good (Test 9) – Strongly Recommended

Percentage of high data quality measurements to produce good velocities		
A key quality control parameter, percent good indicates what fraction of the pings passed the various error thresholds. The percent good test determines whether the data that are being returned are sufficient to provide the required data quality. Different methods are used by different manufacturers. For TRDI, there are percent good 3-beam (PG1[*j*]) solutions (1 beam rejected) and percent good 4-beam (PG4[*j*]) solutions. This test is applied to each depth bin, *i*.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	If PG1(*i*) and PG4(*i*) combined do not exceed a minimum value(PGMINLO), the measurement at that depth bin (i) fails.	IF PG1(*i*)+PG4(*i*) < PGMINLO, flag = 4
Suspect = 3	If PG1(*i*) and PG4(*i*) combined fall in the range between PGMINLO and PGMINHI, the measurement at that depth passes, but is flagged as suspect.	IF PG1(*i*)+PG4(*i*) ≥ PGMINLO AND PG3(*i*)+PG4(*i*) ≤ PGMINHI, flag = 3
Pass = 1	If PG1(*i*) and PG4(*i*) combined exceed a minimum value(PGMINHI), the measurement at that depth bin (*i*) passes.	IF PG1(*i*)+PG4(*i*) > PGMINHI, flag = 1
Test Exception: This applies only to TRDI sensors, excluding beam coordinate configuration.		
Test specifications to be established by the manufacturer. In this case the PGMINLO and PGMINHI values differ depending on the frequency of TRDI system used and the sampling strategy (pings per second and sampling interval). **Example:** Percent good for RDI ADCPs, fail = PG1 + PG4 < 25 and suspect = PG1 + PG4 < 75		

3.4.3 Current Velocity Tests

These tests check the validity of the current velocity (speed and direction) measurements.

Current Speed (Test 10) - Required

Ensure that the current speed is reasonable		
Current speed, CSPD(*j*), is typically provided as a positive value. This test checks for unrealistically high current speed values and is applied to each depth bin, *i*.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	If the current speed, CSPD(*i*) exceeds a reasonable value, SPDMAX, the measurement fails.	IF CSPD(*i*) > SPDMAX, flag = 4
Suspect = 3	N/A	
Pass = 1	If the current speed, CSPD(*i*) is less than or equal to a reasonable maximum value, SPDMAX, the measurement passes.	IF CSPD(*i*) ≤ SPDMAX, flag = 1
Test Exception: None. **Applies to:** All current measurements.		
Test specifications to be established locally by operator. **Example:** SPDMAX=250 cm/s		

Current Direction (Test 11) - Required

Ensure that the current direction is reasonable		
This test ensures that the current direction values fall between 0 and 360 degrees, inclusive. In most systems, 0 is reported as NO current and 360 degrees indicates a current to the north. This test is applied to each depth bin, *i*.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	If current direction CDIR(*i*) is less than 0.00 degrees or greater than 360 degrees, the measurement is invalid.	IF CDIR(*i*) < 0.00 OR CDIR(*i*) > 360.00, flag = 4
Suspect = 3	N/A	
Pass = 1	If current direction CDIR(*i*) is greater than 0.00 degrees and less than or equal to 360 degrees, the measurement is valid.	IF CDIR(*i*) ≥ 0.00 AND CDIR(*i*) ≤ 360.00, flag = 1
Test Exception: None. Applies to all current measurements.		
Test specifications may be adjusted locally depending on their application of 0.00 and 360.00 values. **Examples:** Operators to provide examples as procedures are implemented.		

Horizontal Velocity (Test 12) - Required

Ensure that horizontal velocities are valid measurements.		
Horizontal velocities, u(*i*) and v(*i*), may be represented as components (East-West and North-South; Alongshore and Cross-Shore: Alongshelf and Cross-Shelf, Along-Isobath and Cross-Isobath, etc.) of the current speed and direction. This test ensures that speeds in the respective horizontal directions are valid. Maximum allowed values may differ in the orthogonal directions. This test is applied to each depth bin, *i*.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	Horizontal velocities, u(*i*) and v(*i*), exceed expected maximum values in the two horizontal directions (HVELMAXX and HVELMAXY).	IF ABS[u(*i*)] > HVELMAXX OR IF ABS[v(*i*)] > HVELMAXY, flag = 4
Suspect = 3	N/A	
Pass = 1	Horizontal velocities, u(*i*) and v(*i*), fall within the expected range of values.	IF ABS[u(*j*)] ≤ HVELMAXX AND ABS[v(*j*)] ≤ HVELMAXY, flag = 1
Test Exception: None.		
Test specifications to be established locally by operator. **Example:** Operators to provide examples as procedures are implemented.		

Vertical Velocity (Test 13) – Strongly Recommended

Ensure that vertical velocities are valid measurements		
Vertical velocities, w(*i*), are reported by many ADCPs. They are calculated just like the horizontal velocities, but along the vertical axis. This test is applied to each depth bin, *i*.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	N/A	None
Suspect = 3	If vertical velocity, w(*i*), in a depth bin is greater than 1% of the current speed, CSPD(*i*), in the depth bin, the measurement fails.	IF ABS[w(*i*)] > (0.01*CSPD(*i*)), flag = 4
Pass = 1	If vertical velocity, w(*i*), in a depth bin is less than or equal to 1% of the current speed, CSPD(*i*), in the depth bin, the measurement passes.	IF ABS[w(*i*)] ≤ (0.01*CSPD(*i*)), flag = 1
Test Exception: Alternately, a maximum vertical velocity, VELMAX, may be set and inserted for the (0.01*CSPD(*j*)) value.		
Test specifications may be established locally by operator. **Example:** VELMAX = 0.3m/s		

Error Velocity (Test 14) – Strongly Recommended

Test that the error velocity is below an acceptable threshold

Error velocity, EV(*i*), is a key QC parameter that derives from the 4-beam geometry of an ADCP. Each pair of opposing beams provides one measurement of the vertical velocity and one component of the horizontal velocity, so there are two independent measurements of velocity that can be compared. If the flow field is homogeneous, the difference between these velocities will average to zero. The error velocity can be treated as an indication of errors in the horizontal velocity measurements. This test is applied to each depth bin, *i*.

Flags	Condition	Codeable Instructions
Fail = 4	If the error velocity, EV(*i*), within a depth bin, *i*, exceeds a vendor-provided maximum value, EVMAX, the velocity measurements at that depth fail.	IF EV(*i*) > EVMAX, flag = 4
Suspect = 3	If the error velocity, EV(*i*), within a depth bin, *i*, exceeds a vendor-provided minimum value, EVMIN, but is less than a vendor-provided maximum value, EVMAX, the velocity measurements at that depth pass, but are flagged as suspect.	IF EV(*i*) ≤ EVMAX AND EV(*i*) ≥ EVMIN, flag = 3
Pass = 1	If the error velocity, EV(*i*), within a depth bin, *i*, is less than a vendor-provided minimum value, the velocity measurements at that depth pass.	IF EV(*i*) < EVMIN, flag = 1

Test Exception: Can be used only for ADCPs with 4 or more beams.

Test specifications to be established by the manufacturer.
Example: EVMAX=20, EVMIN=15.

Stuck Sensor (Test 15) - Required

This test checks for observations that do not change with time, and the test can be applied to many variables, such as velocities, directions, or pressure.		
When some sensors and/or data collection platforms (DCPs) fail, the result can be a continuously repeated observation of the same value. This test compares the present observation (PO_n) to a number (REP_CNT_FAIL or REP_CNT_SUSPECT) of previous observations. PO_n is flagged if it has the same value as previous observations within a tolerance value EPS to allow for numerical round-off error. This test may apply to sensor outputs as well as derived values. Note that historical flags are not changed.		
Flags	**Condition**	**Codeable Instructions**
Fail=4	When the five most recent observations are equal, PO_n is flagged fail.	For i=1,REP_CNT_FAIL $PO_n - PO_{n-i}$ < EPS
Suspect=3	It is possible but unlikely that the present observation and the two previous observations would be equal. When the three most recent observations are equal, PO_n is flagged suspect.	For i=1,REP_CNT_SUSPECT $PO_n - PO_{n-i}$ < EPS
Pass=1	Applies for test pass condition	
Test Exception: None.		
Test specifications to be established locally by operator. **Examples:** REP_CNT_FAIL = 5, REP_CNT_SUSPECT= 3		

3.4.4 Overall Profile Tests

These tests use the entire beam length or current profile to check a variety of conditions. They do not apply to a single point acoustic Doppler current meter.

Echo Intensity (Test 16) – Required

Check for echo intensities that may indicate interactions with the surface, bottom, or in-water structures.

This test is a comparison of the echo intensity, EINT(i,j), in bin i, beam j to the echo intensity in the previous bin, EINT(i-1,j). If other beams differ from the tested beam (when comparing adjacent bins) by a pre-described amount, the bin may be flagged.

Flags	Condition	Codeable Instructions
Fail = 4	Two or more beams have adjacent bins that differ by more than an operator-prescribed number of counts, MINEICNT.	For $i \geq 2$ and j=1,2,3,4 If EINT(i,j) - EINT(i-1,j) > MINEICNT BADBEAM++ If BADBEAM ≥ 2, flag = 4
Suspect = 3	One beam has an adjacent bin which differs by more than an operator-prescribed number of counts, MINEICNT.	If BADBEAM = 1, flag = 3
Pass = 1	No other beams have an adjacent bin which differs by more than an operator-provided amount, MINEICNT.	If BADBEAM = 0, flag = 1

Test Exception: None.

Test specifications to be established locally by the operator.
Example: MINEICNT=30.

Echo Intensity Drop-off (Test 17) – Strongly Recommended

Test of echo intensity with distance from the transmitter.		
The echo intensity decreases with distance from the transmitter. At some point, there is not enough energy to provide a valid measure of current speed and direction.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	If Echo Intensity at bin *i*, EI(*i*,*j*) falls below an accepted minimum value (EIMIN) in two or more bins, the data at this bin and farther from the transducer are invalid.	If EI(*i*,*j*) < EIMIN OR EI(*i*+1,*j*) < EIMIN OR EI(*i*+2,*j*) < EIMIN OR EI(*i*+3,*j*) < EIMIN, flag = 4
Suspect = 3	N/A	N/A
Pass = 1	If Echo Intensity, EI(*i*,*j*) exceeds an accepted minimum value (EIMIN) in three or more bins, the data at this bin are valid.	If EI(*i*,*j*) ≥ EIMIN AND EI(*i*+1,*j*) ≥ EIMIN AND EI(*i*+2,*j*) ≥ EIMIN AND EI(*i*+3,*j*) ≥ EIMIN, flag = 1
Test Exception: None.		
Test specifications to be established locally by the operator. **Examples:** Operators to provide examples as procedures are implemented.		

Current Gradient (Test 18) – Strongly Recommended

Test for excessive current speed/direction changes in the vertical profile.		
Current speed is expected to change at a gradual rate with depth. A current difference with depth (CSPDDIF), to be determined locally, should be established and the rate of current speed difference with depth between two bins determined. The same test can be run with current direction.		
Flags	**Condition**	**Codeable Instructions**
Fail = 4	If current speed at bin *i*, CSPD(*i*) exceeds current speed at bin *i*-1, CSPD(*i*-1) by a prescribed amount, CSPDDIF, the data are not valid.	IF ABS[CSPD(*i*)-CSPD(*i*-1)] > CSPDDIF, flag = 4
Suspect = 3	N/A	None
Pass = 1	If current speed at bin *i*, CSPD(*i*) change from the current speed at bin(*i*-1), CSPD(*i*-1), is less than or equal to a prescribed amount, CURDIF, the data are valid.	IF ABS[CSPD(*i*)-CSPD(*i*-1)] ≤ CSPDDIF, flag = 1
Test Exception: None.		
Test specifications to be established locally by the operator. **Examples:** Operators to provide examples as procedures are implemented.		

4.0 Summary

The QC tests in this currents document have been compiled from QARTOD workshops over the years. Test suggestions came from several existing operators with extensive experience. Wherever possible, redundant tests have been merged. In some instances, these tests have been simplified and are less rigorous than those recommended by the established providers of current data. A balance must be struck between the time-sensitive needs of real-time observing systems and the degree of rigor that has been applied to non-real-time systems by operators with decades of QC experience.

The 18 QC tests identified apply to current observations from ADCPs and may apply to other types of current sensors. All tests are either required or strongly suggested, and they fall into four groups: sensor health, signal quality, current velocity, and overall profile. Further, some tests operate on the raw data used to generate current observations, while others apply to the derived current products. The individual tests are described and include codeable instructions, output conditions, example thresholds, and exceptions (if any).

Selection of the proper thresholds is critical to a successful QC effort. Thresholds can be based on historical knowledge or statistics derived from more recently acquired data, but they should not be determined arbitrarily. This manual provides some guidance for selecting thresholds based on input from various operators, but also notes that operators need the subject matter expertise as well as a sincere interest in selecting the proper thresholds to maximize the value of their QC effort.

Sensors continue to become "smarter" and interoperable. For example, some QC procedures may be embedded within the sensor instrumentation package. Significant components of metadata will reside in the instrument and be transmitted either on demand or automatically along with the data stream. Users may also reference metadata through Uniform Resource Locators (URLs) to simplify the identification of which QC steps have been applied to data.

Future QARTOD reports will address standard QC procedures and best practices for all types of common as well as uncommon platforms and sensors for all the U.S. IOOS core variables. Each QC manual is envisioned as a dynamic document and will be posted on the QARTOD website at www.ioos.noaa.gov/qartod/. This process allows for QC manual updates as technology development occurs for both upgrades of existing sensors and new sensors. Separate manuals should be used to discriminate between near real-time data, which might be used for ecosystem-based management, and delayed-mode data, which might be suitable for climate studies.

5.0 References

Bushnell, M., Presentation at QARTOD III: November 2005. Scripps Institution of Oceanography, La Jolla, California.

National Data Buoy Center (NDBC) Technical Document 09-02, Handbook of Automated Data Quality Control Checks and Procedures, National Data Buoy Center, Stennis Space Center, Mississippi 39529-6000. August 2009.

Paris. Intergovernmental Oceanographic Commission of UNESCO. 2013.Ocean Data Standards, Vol.3: Recommendation for a Quality Flag Scheme for the Exchange of Oceanographic and Marine Meteorological Data. (IOC Manuals and Guides, 54, Vol. 3.) 12 pp. (English.)(IOC/2013/MG/54-3). Available online at: http://www.iode.org/index.php?option=com_oe&task=viewDocumentRecord&docID=10762 <http://www.iode.org/index.php?option=com_oe&task=viewDocumentRecord&docID=10762>

UNESCO, 1993. Manual and Guides 26, Manual of Quality Control Procedures for Validation of Oceanographic Data, Section 2.2, Appendix A1: Wave Data. Prepared by CEC: DG-XII, MAST and IOC: IODE. 436pp. Available online at: http://unesdoc.unesco.org/images/0013/001388/138825eo.pdf

U.S. IOOS QARTOD Project Plan – Final. February 18, 2012. Available online at: www.ioos.noaa.gov/qartod

U.S. IOOS, September 2009. A Plan to Meet the Nation's Need for Surface Current Mapping. Available online at: http://www.ioos.noaa.gov/library/surfacecurrentplan9_3lowres.pdf.

U.S. IOOS Office, November 2010. A Blueprint for Full Capability, Version 1.0, 254 pp. www.ioos.noaa.gov/library/us_ioos_blueprint_ver1.pdf

Additional References to Related Documents:

Alliance for Coastal Technologies (ACT) 2012. Accessed September 20, 2012 at http://www.act-us.info/evaluations.php

Argo Quality Control Manual available online at: http://www.argodatamgt.org/content/download/341/2650/file/argo-quality-control-manual-V2.7.pdf

National Oceanographic Partnership Program (NOPP) January 2006. The First U.S. Integrated Ocean Observing System (IOOS)Development Plan – A report of the National Ocean Research Leadership Council and the Interagency Committee on Ocean Science and Resource Management Integration. The National Office for Integrated and Sustained Ocean Observations. Ocean US Publication No. 9. Available online at: http://www.usnfra.org/documents/IOOSDevPlan_low-res.pdf

Crout, R., D. Conlee, D. Gilhousen, R. Bouchard, M. Garcia, F. Demarco, M. Livingston, C. Cooper, and R. Raye, 2006: Real-time oil platform ocean current data in the Gulf of Mexico: an IOOS industry partnership success story. Proc. AMS, 22nd International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology.

Bender, L.C. and S.F. DiMarco. 2008. Quality control and analysis of acoustic Doppler current profiler data collected on offshore platforms of the Gulf of Mexico. U.S. Dept. of the Interior, Minerals Mgmt. Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2009-010. 63 pp. available at: http://www.data.boem.gov/PI/PDFImages/ESPIS/4/4888.pdf

GTSPP Real-Time Quality Control Manual, First Revised Edition. UNESCO-IOC 2010. (IOC Manuals and Guides No. 22, Revised Edition.) (IOC/2010/MG/22Rev.) English only Available online at: http://www.nodc.noaa.gov/GTSPP/document/qcmans/MG22rev1.pdf

Haines, S., R. Crout, J. Bosch, W. Burnett, J. Fredericks, D. Symonds and J. Thomas, 2011. A summary of quality control tests for waves and in situ currents and their effectiveness, in IEEE/OES 10th Current, Waves and Turbulence Measurements (CWTM), 100 - 106 DOI: 10.1109/CWTM.2011.5759534. Available online at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5759534

Hammarklint, T., D. Kassis, H. Wehde, L. Rickards. April 2010. Real time quality control of current measurements. GMES Marine Core Service, MyOceans Project: WP15. (http://www.myocean.eu.org).

Hankin, S. and DMAC Steering Committee, 2005. Data management and communications plans for research and operational integrated ocean observing systems: I interoperable data discovery, access, and archive, Ocean.US, Arlington, VA, 304 pp. http://dmac.ocean.us/dacsc/imp_plan.jsp

Integrated Marine Observing System (http://code.google.com/p/imos-toolbox/)

Moore, A.N, D.L. Stewart, March 2003. "The effects of mobile scatterers on the quality of ADCP data in differing marine environments." Proceedings of the IEEE/OES Seventh Working Conference on Current Measurement Technology. p. 202-206.

QARTOD I-V Reports 2003-2009. Available online at: http://www.ioos.noaa.gov/qartod/

Recommendations for in-situ data Real Time Quality Control, Authors: Sylvie Pouliquen and the DATA-MEQ working group. (http://www.eurogoos.org/documents/eurogoos/downloads/rtqc.pdf)

Taylor, J.A.; Jonas, A.M. "Maximising data return: Towards a quality control strategy for managing and processing TRDI ADCP data sets from moored instrumentation", Current Measurement Technology, 2008. CMTC 2008. IEEE/OES 9th Working Conference, p. 80–88. Available online at: http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=4480848

Thomson, R. 2001. Data Analysis Methods in Physical Oceanography. Gulf Professional Publishing, Second Edition, 638pp. Available online at: http://books.google.com/books?id=A6ew-bJDIDIC&pg=PA83&lpg=PA83&dq=Acoustic+Doppler+Current+Profiler+book&source=bl&ots=PwSf29Bbuo&sig=LxTDjtmzKFVCgF8ZT0kwme964TU&hl=en&ei=WLtOTcSPFcP98Aaez9GCDw&sa=X&oi=book_result&ct=result&resnum=5&sqi=2&ved=0CDYQ6AEwBA#v=onepage&q=Acoustic%20Doppler%20Current%20Profiler%20book&f=false

Supporting Documents Found on the QARTOD Website:

(http://www.ioos.noaa.gov/qartod/)

U.S. IOOS Development Plan
(file name: ioos_devplan)

NDBC Handbook of Automated Data Quality Control
(file name: NDBCHandbookofAutomatedDataQualityControl2009)

Data Quality Control in the U.S. IOOS
(file name: IOOS CWP_Lankhorst_Data_QC.doc)

Requirements for Global Implementation of the Strategic Plan for Coastal GOOS - Panel for Integrated Coastal Observation (PICO-I)
(file name: Requirements_for_Global_Implementation_of_the_Strategic_Plan_for) Coastal) GOOS_GOOS-193)

Integrating Standards in Data QA/QC Into OpenGeospatial Consortium Sensor Observation Services
(file name: IEEE Ocean09Bremen)

Appendix A. Quality Assurance

A major pre-requisite for establishing quality control standards for current measurements is a strong quality assurance program. Remember the mantra that good QC requires good QA, and good QA requires good scientists, engineers, and technicians.

A good QA effort continuously seeks to ensure that end data products are of high value and strives to prove they are free of error. Operators should seek out partnering opportunities to inter-compare systems by co-location of differing sensors, thereby demonstrating high quality by both to the extent that there is agreement and providing a robust measure of observation accuracy by the level of disagreement. Operators should also, if possible, retain an alternate sensor or technology from a second vendor for similar in-house checks.

The following sections suggest ways to ensure QA by using specific procedures and techniques.

A.1 Sensor Calibration Considerations

Observations must be traceable to one or more accepted standards through a calibration performed by the manufacturer or the operator. If the calibration is conducted by the manufacturer, the operator must also conduct some form of an acceptable calibration check. For instance, the instrument could be damaged in shipment from the manufacturer or have been exposed to a temperature outside its prescribed operating range.

An often overlooked calibration or calibration check can be performed by consensus standard. For example, deriving the same answer (within an acceptable level of accuracy) from four different sensors of four different manufacturers, preferably utilizing several different technologies, constitutes a perfectly acceptable reference. Because of the trend towards corporate conglomeration, those wishing to employ a consensus standard should ensure that the different manufacturers are truly independent.

A.2 Sensor Comparison

An effective QA effort continuously strives to ensure that end data products are of high value and to prove they are free of error. Operators should seek out partnering opportunities to inter-compare systems by co-locating differing sensors. Agreement of multiple systems would provide a robust observation, while disagreement may offer a measure of data uncertainty. If possible, operators should retain an alternate sensor or technology from a second vendor for similar in-house checks. For resource-constrained operators, however, it may not be possible to spend the time and funds needed to procure and maintain two systems. For those who do so and get two different results, the use of alternate sensors or technologies provide several important messages: a) a measure of the accuracy and precision achieved by an operator; b) a reason to investigate, understand the different results, and take corrective action; and c) increased understanding that when variables are measured with different technologies, different answers can be correct, and they must be understood in order to properly report results. For those who succeed, the additional sensors provide a highly robust demonstration of operator capability. Such efforts form the basis of a strong QA/QC effort. Further, it provides the operator with an expanded supply source, permitting less reliance upon a single vendor and providing competition that is often required by procurement offices.

A.3 Bio-fouling and Corrosion Prevention Strategies

Bio-fouling is the most frequent cause of sensor failure, so the following strategies may be useful for ameliorating the problem:

- Use anti-fouling paint with the highest copper content available (up to 75%) when possible (not on aluminum).
- Wrap body of sensor with clear packing tape for a small probe or plastic wrap for a large instrument. This keeps the PVC tape from leaving residue on the sensor. Heavy PVC underground cable tape is the best for bad biofouling.
- Wrap with copper tape (again, beware of aluminum).
- Coat with zinc oxide (Desitin ointment - – manufactured by Johnson and Johnson Inc.; 1 Johnson and Johnson Plaza, New Brunswick, NJ 08933 (732) 524-0400).
- Remember that growth is sensor, depth, location, and season dependent; plan instrument recovery frequency accordingly.
- Plan for routine changing or cleaning of sensor as necessary.
- Check with calibration facility on which anti-foulants will be handled (allowed) by the calibrators.
- Avoid or isolate dissimilar metals.
- Maintain sacrificial anodes and ensure they are properly installed (good electrical contact).
- Maximize use of non-metallic components.
- Use UV-stabilized components that are not subject to sunlight degradation.

A.4 Common QA Considerations

The following lists suggest ways to ensure QA by using specific procedures and techniques:

- Pre-deployment calibrations on every sensor
- Post-deployment calibrations on every sensor, plus in-situ comparison before recovery
- Periodic calibration of ready-to-use spares
- Monitor with redundant sensors whenever possible
- Take photos of sensor fouling for records
- Record all actions related to sensors – calibration, cleaning, deployment, etc.
- Monitor battery voltage and watch for unexpected fluctuations

When evaluating which instrument to use, consider these factors:

- Selection of a reliable and supportive manufacturer and appropriate model
- Operating range (i.e., some instruments won't operate at certain temperatures, pressures, or depths)
- Resolution/precision required
- Sampling frequency – how fast sensor can take measurements
- Reporting frequency – how often the sensor reports the data
- Response time of the sensor – sensor lag – time response
- Instrument check – visual inspection for defects, bio-fouling, etc.
- Power check – master clock, battery, etc. – variability in these among sensors
- Standardize sensor clock to a reference such as GPS timing
- Capability to reveal a problem with data

When evaluating which specifications must be met:

- State the expected accuracy
- Determine how the sensor compares to the design specifications
- Determine if the sensor meets those specifications
- Determine whether result is good enough (fit for purpose: data are adequate for nominal use as preliminary data)

General comments regarding QA procedures:

- A diagram (http://www.ldeo.columbia.edu/~dale/dataflow/), contributed by Dale Chayes (LDEO) provides a visual representation of proper QA procedures.
- Require serial numbers and model ID from the supplier.
- Do not make the checklist so detailed that it will not be used.
- Do not assume the calibration is perfect (could be a calibration problem rather than a sensor problem).
- Keep good records of all related sensor calibrations and checks (e.g., temperature).
- Use NIST-traceable instrumentation when conducting calibrations or calibration checks.
- A sensor that maintains an internal file of past calibration constants is very useful since it can be downloaded instead of transcribed manually introducing human error.
- The calibration constants or deviations from a standard should be plotted over time to determine if the sensor has a drift in one direction or another. A sudden change can indicate a problem with the sensor or the last calibration.

A.5 QA Levels for Best Practices

A wide variety of techniques are used by operators to assure that sensors are properly calibrated and operating within specifications. While all operators must conduct some form of validation, there is no need to force operators to adhere to one single method. Nevertheless, operators should always strive to achieve the best possible level of QA. If they are unable to do so, then they should provide valid justification. Operators must show due-diligence in maintenance of their systems. A balance exists between available resources, level of proficiency of the operator, and target data reproducibility requirements. The various techniques span a range of validation levels and form a natural hierarchy that can be used to establish levels of certification for operators (table A-1). The lists in the following sections suggest ways to ensure QA by using specific procedures and techniques.

Table A-1. Best practices indicator for QA

QA Best Practices Indicator	Description
Good Process	Sensors are exchanged and/or serviced at sufficient regular intervals. Sensors are pre- and post-deployment calibration checked.
Better Process	Good process, plus an overlapping operational period during sensor swap-out to demonstrate continuity of observations.
Best Process	Better process, and follow a well-documented protocol or alternative sensors to validate in-situ deployments. Or, the better process employing manufacturer conducted pre- and post-calibrations.

A.6 Additional Sources of QA Information

Current sensor operators also have access to other sources of QA practices and information about a variety of instruments. For example, the Alliance for Coastal Technologies (ACT) serves as an unbiased, third party testbed for evaluating sensors and platforms for use in coastal and ocean environments. ACT conducts instrument performance demonstrations and verifications so that effective existing technologies can be recognized and promising new technologies can become available to support coastal science, resource management, and ocean observing systems (ACT 2012). The NOAA Ocean Systems Test and Evaluation Program (OSTEP) also conducts independent tests and evaluations on emerging technology as well as new sensor models. Both ACT and OSTEP publish findings that can provide information about QA, calibration, and other aspects of sensor functionality. The following list provides links to additional resources on QA practices.

- Manufacturer specifications and supporting Web pages/documents
- QARTOD http://www.ioos.noaa.gov/qartod/
- ACT http://www.act-us.info/
- CO-OPS http://tidesandcurrents.noaa.gov/pub.html under the heading Manuals and Standards
- WOCE http://woce.nodc.noaa.gov/wdiu/
- NDBC http://www.ndbc.noaa.gov/

The following samples provide hints for development of deployment checklists taken from QARTOD IV:

Pre-deployment QA Checklist

- ❒ Read the manual.
- ❒ Establish, use, and submit (with a reference and version #) a documented sensor preparation procedure (protocol). Should include cleaning sensor according to the manufacturer's procedures.
- ❒ Calibrate sensor against an accepted standard and document (with a reference and version #).
- ❒ Compare the sensor with an identical, calibrated sensor measuring the same thing in the same area (in a calibration lab).
- ❒ View calibration specifications with a critical eye (don't presume the calibration is infallible). Execute detailed review of calibrated data.
- ❒ Check the sensor history for past calibrations, including a plot over time of deviations from the standard for <u>each</u> (this will help identify trends such a progressively poorer performance). Maintain control of the plotted calibrations.
- ❒ Check the sensor history for past repairs, maintenance, and calibration.
- ❒ Consider storing and shipping information before deploying.
    - Heat, cold, vibration, etc.
- ❒ Provide detailed documentation when necessary.
- ❒ Record operator/user experiences with this sensor after reading the manual.
- ❒ Search the literature for information on your particular sensor(s) to see what experiences other researchers may have had with the sensor(s).
- ❒ Establish and use a formal pre-deployment checklist.
- ❒ Ensure that technicians are well-trained. Use a visual tracking system for training to identify those technicians who are highly trained and then pair them with inexperienced technicians. Have data quality review chain.

Deployment Checklist

- ❒ Scrape bio-fouling off platform.
- ❒ Verify sensor serial numbers.
- ❒ Deploy and co-locate multiple sensors (attention to interference if too close).
- ❒ Perform visual inspection; take photos if possible (verify position of sensors, connectors, fouling, cable problems).
- ❒ Verify instrument function at deployment site prior to site departure. Allot sufficient time for temperature equilibration.
- ❒ Monitor sensors for issues (freezing, fouling).
- ❒ Automate processing so you can monitor the initial deployment and confirm the sensor is working while still on-site.
- ❒ Specify date/time for all recorded events and check to ensure proper time is set. Use GMT or UTC.
- ❒ Check software to ensure that the sensor configuration and calibration coefficients are correct. Also check sampling rates and other timed events, like wiping and time averaging.
- ❒ Visually inspect data stream to ensure reasonable values.
- ❒ Compare up and down casts and/or dual sensors (if available).
- ❒ Note weather conditions and members of field crew.

Post-deployment Checklist

- ❒ Take pictures of recovered sensor as is for metadata
- ❒ Check to make sure all clocks agree or, if they do not agree, record all times and compare with NIST.
- ❒ Post-calibrate sensor and document before and after cleaning readings.
- ❒ Perform in-situ side by side check using another sensor.
- ❒ Provide a mechanism for feedback on possible data problems and/or sensor diagnostics.
- ❒ Clean and store the sensor properly or redeploy.
- ❒ Visually inspect physical state of instrument.
- ❒ Verify sensor performance by:
    - Checking nearby stations;
    - Making historical data comparisons (e.g., long-term time-series plots, which are particularly useful for identifying long-term bio-fouling or calibration drift.)

Appendix B. In-Situ Currents Manual Team and Reviewers

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